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COMPARING GARMIN FORERUNNER 405CX GPS AND NIKE +IPOD TO
ACCURATELY MEASURE ENERGY EXPENDITURE, DISTANCE, AND SPEED OF
OVERGROUND RUNNING

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COMPARING GARMIN FORERUNNER 405CX GPS AND NIKE +IPOD TO ACCURATELY MEASURE ENERGY EXPENDITURE, DISTANCE, AND SPEED OF OVERGROUND RUNNING

CHRISTINE MALLULA

ABSTRACT

Accurate measurement of energy expenditure, distance, and speed are desired by many runners. There are many commercially available devices for measuring these components in overground running. **Purpose:** The purpose of this research study was to compare the accuracy of distance, speed, and energy expenditure of overground running with two different devices: the Garmin Forerunner 405CX GPS and the Nike + iPod. **Methods:** Subjects consisted of 15 runners recruited from the Cleveland running community. The subjects were composed of 9 males and 6 females ranging in age from 18-55 years old. After a quarter mile calibration, the subjects ran a 3 mile measured course on an outdoor path. All devices were started simultaneously and compared. Inferential statistics (one-way ANOVA) was used to analyze the data. **Results:** A significant difference for energy expenditure was seen between the GPS and indirect calorimeter ($p=.007$) and also between the GPS and the Nike ($p=.008$). A significant difference in distance was seen between the Nike and the measured distance ($p=.0001$) and the GPS to the Nike ($p=.0001$). **Conclusion:** The GPS unit can be an accurate measuring tool for distance and the Nike can be accurate for measuring energy expenditure in overground running.

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CHAPTER I

INTRODUCTION

Physical activity is important for the prevention of many diseases. The Surgeon General recommends an accumulation of at least 30 minutes of physical activity at moderate-intensity most, if not every day of the week¹⁹. As a society, Americans are spending more time being sedentary due in part to technology in spending less energy for transportation and occupation¹⁸. US trends data reports a decrease in energy expended and an increase in the prevalence of obesity since the 1970s¹⁰. Therefore, it seems important to increase energy expenditure and to find ways to measure the amount of energy expended during activity to better gauge how active one should be.

Measuring physical activity and energy expenditure have more potential value for some people than just to measure health benefits and maintenance¹⁸. Measuring energy expenditure during exercise may be useful for some athletes to help with weight loss or proper nutrition during training. Measurement of distance and speed may also be sought after by athletes to help perfect their training routines.

Factoring together aerobic and biomechanical needs, the amount of energy used per unit distance is the energy cost needed for running²⁰. The estimation of oxygen uptake (VO_2) can be used to find the metabolic power used during running²⁰. The amount of force that is generated during locomotion is dependent on an individual's speed, gait, and size. This affects power needed for movement and in turn increases energy demand¹.

Running style and trainability may affect how much energy is expenditure during running^{20,13}. Changes in running gait may also alter the mechanical aspects of running by changing the force generated by the muscles used during the run, therefore, changing energy expended¹. Running gait may be altered slightly on treadmills, which is the usual method for testing subjects for running mechanics. However, gait changes may vary more while running outdoors which may be due to differences in stride length, elevation changes, stride to stride variances, and biomechanical efficiencies²¹.

“The gold standard” for measuring energy expenditure, direct calorimetry, uses a large chamber to measure the body's heat production. This is costly and not readily available¹⁷. Therefore, indirect calorimetry is the method most widely used. The indirect method measures gas exchange from the lungs. The expired air is measured for volume and changes in oxygen and carbon dioxide percentages. When analyzed one can determine what the energy expenditure was during the allotted time¹⁷.

With the invention of the portable systems for metabolic gas analysis researchers are able to leave the laboratory and test subjects in a variety of settings. These portable units are equipped with a mask and flow meter with a turbine, portable transmitting unit which is attached to a chest harness, and a receiving unit. The system uses an oxygen

analyzer and a thermostatically controlled carbon dioxide analyzer which analyzes gas samples¹⁶.

Since indirect calorimetry equipment is too expensive and technical for the average person to use, other devices have been introduced to try to estimate energy expenditure. These devices are small and easy to use for the average consumer. Some of these devices offer additional functions to help measure fitness and allow individuals to track training and performance, especially for runners. The technology available today offers a variety of components which include measuring heart rate (HR), steps, cadence, speed, and distance. Some of the current technological choices for measuring physical performance are satellite global positioning system (GPS) units, HR monitors, pedometers, and accelerometers. Some products have a combination of two or more of these components in one unit.

Challenges in accurately measuring speed and distance in outdoor activities may arise from factors such as terrain and location. Techniques traditionally used to measure distance have been tape measures or measuring wheels. More technological methods include optical systems using laser measurements. Speed, on the other hand, has been measured using stopwatches or light gates but these are only able to measure average speed. In the 1990s, introduction of the portable Global Positioning System (GPS) changed the way speed and distance could be measured. GPS was originally designed to be used for military purposes²². There are two different frequencies that are available for GPS units today, one reserved for use by the military and one with free access for anyone²¹. GPS uses 24 satellites orbiting the earth to emit encrypted radio signals with coded sequences 24 hours a day worldwide in all weather conditions which are sent to the

GPS unit. The units then decode them giving the user an exact reading of time and position by calculating the geometric positions of the satellites in relationship to the GPS unit^{21,22}. Accuracy of these commercially available units has been noted to be affected by atmospheric conditions and local obstructions²².

Other portable devices that can be used to estimate distance, speed, and energy expenditure are pedometers and accelerometers. Pedometers have been around for centuries and are used primarily to count steps. Pedometers have been shown to be inaccurate in estimating energy expenditure since they are one-dimensional and only measure the lower limbs of the body. Accelerometers measure three-dimensions of the body and are therefore more accurate in estimating energy expenditure¹⁸. Pedometers rely on stride length for measurement, whereas accelerometers use changes in force and electrical responses to pressure changes¹⁸.

Accelerometers are able to detect acceleration through actual magnitude and have the ability to record it. Pedometers, on the other hand, are less sophisticated in that they are unable to measure or record acceleration. The information from an accelerometer can be monitored for a period of time, stored, and then analyzed at a later time⁶.

Wireless HR monitors were originally marketed towards coaches and athletes to assist in measuring training efficiency. Realizing their potential, exercise scientists began using HR monitors in research studies¹⁴. There are certain limiting factors to obtaining an accurate HR with a HR monitor which may affect outcome values of physical activities. Stress and hydration level, as well as outdoor temperature and humidity may be factors affecting outcome values. Other factors include type of exercise as well as

training status and gender³. The current innovation in HR monitors now includes features such as intensity guidance and the ability to estimate energy expenditure¹⁴. HR monitors are now available on other devices such as GPS units to assist in achieving an accurate measure of intensity and estimated energy expenditure.

New technology is always being developed. The invention of the iPod created a whole new running retail product market. Ninety percent of all MP3 players sold today are iPods²⁴. More runners are incorporating these devices into their running routine. Nike teamed up with Apple to create the Nike + Sport kit (Nike +iPod), which includes a sensor which connects to an iPod unit and an accelerometer⁵. The Nike + iPod kit was the number one selling running accessory in 2007²⁴. The kit is a less expensive alternative to GPS units that are on the market⁵. GPS units retail anywhere from \$150-\$400 and the Nike +iPod retails for around \$30. The Nike system does require an iPod which requires an extra cost starting around \$100. The technology from the GPS units or the Nike +iPod make recording progress and workouts much easier than using pen and pencil as the information gathered from the devices can be downloaded to computers⁵.

A few factors one might consider in deciding which unit to purchase is what type of activity will be measured, terrain of the activity, location such as indoors or outdoors, and cost. However, accuracy of the equipment should be the largest deciding factor in the purchasing process.

Since most people do not conduct their physical activity in a controlled laboratory atmosphere, it is important to assess devices in a setting appropriate for the majority of the population (i.e. outdoors). Distance, speed, and energy expenditure of overground

running can be measured by many devices such as the Garmin Forerunner 405CX GPS and the Nike + iPod. Being outdoors though, there are factors to consider such as terrain, atmospheric conditions, as well as physiologic conditions that can affect the accuracy of the devices^{3,22}.

Purpose

The purpose of this research study was to compare the accuracy of distance, speed, and energy expenditure of overground running in two different devices: Garmin Forerunner 405CX GPS and the Nike + iPod.

Null Hypothesis

1. It was hypothesized that there will be no significant difference between the in Garmin (Forerunner 405CX GPS) and the Nike + iPod for determining distance, speed, or energy expenditure.
2. It was hypothesized that there will be no difference in estimated energy expenditure of the Garmin (Forerunner 405CX GPS) and the Nike + iPod when compared to indirect calorimetry.
3. It was hypothesized that there will be no gender difference in energy expenditure, distance, or speed using the Garmin (Forerunner 405CX GPS) and the Nike + iPod.

CHAPTER II

LITERATURE REVIEW

Measuring energy expenditure, distance, and speed may be important factors for some athletes. Finding devices that are both portable and accurate is essential for proper training and recording of progress. Heart rate monitors and accelerometers have been used for years and many studies have been done to measure their validity. One new device that is becoming more readily available but still needs more research is the portable GPS unit.

In a 2004 study³, researchers enrolled 20 active college subjects (m=10, f=10) were used to measure the accuracy of the Polar S410 HR monitor. Each subject was measured during rest, a maximal test conducted on a treadmill, and nine submaximal tests measured on a treadmill, cycle ergometer, and rowing ergometer. For the first test, the HR monitor used a predicted max VO_2 and HR as recommended by the manufacturer. These were entered into the unit along with height, weight, gender, physical activity level, and resting HR. The second test used measured max VO_2 and HR which were

entered into an identical unit along with each subject's personal information. The subjects performed the nine submaximal tests wearing both HR monitors at the same time as well as an indirect calorimeter. The submaximal tests consisted of ten minutes on the treadmill, cycle ergometer, and rowing ergometer at a self-selected rate of perceived exertion of 3-7 on a 0-10 scale.

In the males, the results showed no significant difference between any of the three methods in estimating energy expenditure; using predicted max VO_2 and HR (-0.1 kilocalories per minute), actual measurement VO_2 and HR (-0.5 kilocalories per minute), or indirect calorimetry. However, in females, the predicted measurement overestimated (+2.4 kilocalories per minute) the measured energy expenditure. The actual max VO_2 and HR improved the measurement, however, a small overestimation was still observed on the treadmill (+0.6 kilocalories per minute) and the cycle (+1.2 kilocalories per minute).

In a 2005 study¹², researchers used mode of exercise, body composition, and training in 115 active individuals, (m=72, f=43) aged 18-45 years, to determine the effects of HR and physical activity on energy expenditure. The study used measured max VO_2 and HR to predict energy expenditure during a steady-state exercise test. They also used age, gender, body mass, and HR for their prediction. The individuals were assessed during either three, 10 minute treadmill tests (n=46) or three, 15 minute cycle ergometer tests (n=69) using VO_2 (35%, 62% and 80% max) and HR (57%, 77% and 90% max), respectively. Max VO_2 data was not used in all tests to calculate the results.

During each stage a HR monitor (Polar Vantage) and an indirect calorimeter (Oxycon Alpha) was used to collect data. The relationship between HR and energy expenditure was best predicted by gender, HR, body mass, max VO_2 , and age. The accuracy for the measured and estimated energy expenditure was higher using measured max VO_2 ($r=0.913$) than without using max VO_2 ($r=0.857$). This study suggests, with adjusting for age, gender, body mass, and fitness level (VO_2), HR can be an accurate way to estimate energy expenditure during physical activity.

In a 1999 study⁷, researchers measured the relationship between HR and oxygen uptake (VO_2) in the estimation of energy expenditure during exercise. The study consisted of 87 subjects (m=45, f=42), with a mean age of 38 years, who participated in 4 different tests. Two of the tests were submaximal consisting of a 10 minute steady-state walk on the treadmill or on a cycle ergometer. The other 2 tests were incremental sessions consisting of a maximal uphill walk test on the treadmill and a submaximal cycling ergometer test. The tests were done on non-consecutive days. Indirect calorimetry (Medikro 202) was used to collect respiratory gases during the tests. Estimated energy expenditure was calculated using the subject's VO_2 and carbon dioxide production (VCO_2) measured from the calorimeter. Predicted energy expenditure was found by using HR, body weight, and gender or by using HR, age, and gender. The last 8 minutes of the steady-state exercise and the last minute of the incremental tests were used for the calculation of energy expenditure. The predicted and measured energy expenditure was compared during the steady-state of the exercises.

A three-way interaction was found between HR, body weight, and gender and another between HR, age, and gender. Therefore all three of these are needed to gain an

accurate prediction for energy expenditure. Because men have more body mass it was expected that they would have greater energy expenditure during the same exercise as that of females, which is why gender is important to input into the device.

In a 2008 study²², researchers used three healthy and physically active subjects (m=2, f=1), aged 22-38 years, to test the accuracy of GPS measurements. The GPS unit used for this study was a commercially available unit (GPS-BT55). The study used four different tests to assess the validity of distance, speed on a straight course, speed on a circular path, and position. The distance measurement was tested 40 times on a 100 meter course which provided a 95% accuracy result. The distance range measured for the 100 meter course was 99.48 to 101.11 meters.

The speed measurement on the straight course obtained results from 337 tests on a 60 meter course. Two different methods were used, Doppler shift and calculations in speed over time and were compared to actual speed data obtained. The actual speeds for the Doppler shift were 90.8% accurate within $0.1 \text{ m}\cdot\text{s}^{-1}$ with the speed measured by a chronometer and 97.9% accurate within $0.2 \text{ m}\cdot\text{s}^{-1}$. The actual speeds measured from the speed over time measurements were 66.5% accurate within $0.1 \text{ m}\cdot\text{s}^{-1}$ and 94.4% within $0.2 \text{ m}\cdot\text{s}^{-1}$.

The curved path measurement used 34 tests following a marked line of a circumference of ten meters in radius. Doppler shift and calculations in speed over time were used in this study also. Timing gates at set distances were used to provide feedback of actual speed at 15, 25, 35, and 45 meters. The results from the Doppler shift were 71.1% and were within $0.1 \text{ m}\cdot\text{s}^{-1}$, and 86.7% were within $0.2 \text{ m}\cdot\text{s}^{-1}$. The results from the

actual speeds were 53.1% and were within $0.1 \text{ m}\cdot\text{s}^{-1}$, and 88.3% were within $0.2 \text{ m}\cdot\text{s}^{-1}$. These results did not factor in any change from body position leaning that may occur during a fast circular sprint which may have affected the GPS position on the course.

The final experiment tested position measurement which placed the GPS unit on a geodetic point for one hour. This measured data points and spatial distributions as compared to its known coordinates. This measurement provided 86.5% accuracy within 1.5 meters, and 99.89% accuracy within 2 meters of the known point.

The study showed that GPS units accurately estimate speed during overground running and accurately are measured at an actual geodetic point. Runners using GPS units should be aware of inaccuracies that may occur while running on curved paths and that the satellite signal can be lost while under tree cover and in tunnels.

In a 2007 study⁴, researchers determined if a low-cost GPS unit (Garmin GPS 60) can accurately measure speed and distance of walking during a period of both walking and rest. Thirty subjects aged 18-46 years performed a prescribed walking protocol while wearing the GPS unit in a backpack. Within each of these walking sessions, the subjects were prescribed bouts walking at a rate chosen by the subjects.

Three experiments were conducted simultaneously. The first measured the accuracy of the signal processing by detecting speed during the walking and resting bouts. The second measured the validity and applicability of the methods used in the first experiment using a different series of the walking protocols. The third measured the accuracy of speed and distance from the GPS recordings as compared to actual measured speed by chronometry and distance.

The first experiment consisted of walking on a 400 meter outdoor track for 2 minutes, 4 minutes, 30 seconds, 15 seconds, 1 minute, and 8 minutes separated by rest periods of 30 seconds, 15 seconds, 4 minutes, 2 minutes, 1 minute, and 8 minutes. The GPS unit was started and stopped 15 minutes prior to and after the walking tests. The GPS unit during this test showed 89.8% accuracy while using a low-pass filter, a high-pass filter, and artifact processing.

The second experiment consisted of walking bouts on a flat path with minimal tree cover at a local park for 18 and 20 minutes. The GPS was turned on 10 minutes prior to the start of the walking bout to initialize it. The GPS unit showed an accuracy of 97.1% while using a manual post-processing method.

The third experiment consisted of a walking prescription of walking on an outdoor track for 2000 meters. The subjects walked consistently for 100, 200, 300, or 400 meters with a 30 second rest between distances. The GPS unit had an excellent relationship between actual speed and processed distance ($r^2=1.000$) and between actual and processed speeds ($r^2=0.947$).

The GPS was shown to be accurate in measuring outdoor walking. Both the walking bouts and rest periods were easily recognized. The unit was accurate in measuring both speed and distance during the different walking bouts.

In a 2001 study²¹, researchers tested the accuracy of a GPS unit (Leica Geosystems) in assessing external mechanical work in subjects walking outdoors. Five subjects (m=3, f=2) aged 24 to 28 years participated in this experiment. Prior to and after the experiment the subjects lied down for 20 minutes wearing an indirect calorimeter

(Cosmed K4b²) to measure metabolic rate. The subjects then walked on an outdoor track while wearing the GPS unit and calorimeter for 5 minutes at different strides dictated by a metronome set at 70, 90, 110, or 130 steps per minute. The subjects kept the same gait and maintained steady state energy expenditure. A final test was conducted allowing the subject to set the walking pace.

The data was analyzed using the data collected during the steady state period, which was the last 2 minutes of exercise. Expected results were found in a linear relationship between energy expenditure and total mechanical power ($r=0.95$) using the GPS device. However, an over-estimation of mechanical power and higher net mechanical efficiency was seen in this study. This may have been caused from the antennae of the GPS device swinging during the tests. This also could have been responsible for an underestimation of the energy exchanged between potential and kinetic energy.

In a 2004 study², researchers used 25 runners ($m=15$, $f=10$) aged 21-47 years to measure the accuracy of speed and distance during running with the Nike Triax Elite accelerometer. Three separate one mile (1.61 kilometers) runs were conducted on a treadmill. The elevation for the three runs was 0%, -5%, or 5%. The accelerometer was worn on the top of the shoe and the information from the accelerometer was transmitted to a watch worn by the subject. The device was calibrated on an indoor track where the subject ran 880 yards.

During the treadmill tests the study found that an over-estimation for distance from the level to uphill to be 13.56 meters. It found less accurate distance from the level

to the downhill, under-estimating the distance by 24.99 meters. The most inaccurate distance measurement, however, occurred in the change from uphill to downhill which under-estimated by 38.71 meters. This may have been due to the extreme change from a 5% grade down to a -5% grade.

The speed measurement for this test was compared to the display on the treadmill during the different grades tested. For the three tests, the measurement of speed showed a difference of less than 0.16 kilometers per hour, indicating this was an accurate method for measuring speed.

In a 2000 study⁶, researchers determined the validity of an accelerometer in estimating the metabolic cost of several every day activities. The subjects were between 30 and 50 years old and able to physically participate in all of the activities. Twenty five volunteers (m=10, f=15) participated in this study. The activities selected were walking, playing golf, housecleaning, and doing yard work. This study's goal was to examine the accuracy of an accelerometer during non-traditional uses to measure its usability in calculating energy expenditure in "free-living situations".

A portable indirect calorimeter (TEEM 100) and three motion sensors, a uniaxial accelerometer (CSA model 7164), a triaxial monitor accelerometer (Tritrac), and a pedometer (Digiwalker SW-701) were attached to the waist of the subjects and used to assess all of the activities. The first test performed was a walk test. The subjects walked on an indoor track for four sessions at four different self-selected speeds: leisurely, comfortable, moderate, and brisk. Five minute sessions were conducted with five minutes of rest between sessions. Pace and stride were measured during each lap. The

second test consisted of each subject participating in two holes of golf while using a pull cart for their clubs. The third test involved housecleaning and yard work tasks. This involved performing five minutes each of washing windows, dusting, vacuuming, mowing the lawn with a push mower, and planting shrubs.

The walking session's accuracy for energy expenditure was higher ($r = .77$ and $r = .89$) as compared to the other activities combined ($r = .59$ and $r = .62$) for each of the accelerometers, respectively. The activities combined showed energy expenditure was underestimated (30.5-56.8%) for the two accelerometers from measured METS and predicted METS. Accelerometers are a good way to measure walking and lower limb exercises. However, the inability to measure upper body movements and changes in terrain will lead to inaccuracies in energy expenditure measurements.

In a 2008 study¹¹, researchers measured accelerometer wear time for its reliability in moderate to vigorous physical activity in overweight and obese adults. A pre-phase was monitored and participants who lost 4 kg were invited to participate in a post-phase for a 6 month weight loss program. The subjects consisted of 1592 participants in the pre-phase and 1070 participants in the post-phase study which consisted of a weight loss maintenance trial consisting of physical activity and diet. Physical activity was measured and assessed using a RT3 triaxial accelerometer collecting data in one minute increments. The accelerometer was worn during waking hours for one consecutive week. Physical activity of moderate to vigorous levels, greater than 3 metabolic equivalents, was assessed for bouts of 10 minutes during a wear time of 6 or 10 hours per day. The data analyzed consisted of the first 4 days of measured activity which included a weekend day.

The reliability for each of these tests showed similar results for the 6 or 10 hour measurements. Therefore, the researchers used the 6 hour time for the final analysis of the physical activity estimates. Interclass correlations between person variance and total variance were used to determine the outcome. According to the Spearman-Brown prophecy formula, 9 to 13 days are needed to achieve a reliability of 0.70 and 16 to 23 days are needed to achieve a reliability of 0.80 for the pre-phase, and 9 to 16 days for both 0.70 and 0.80 reliability for the post-phase.

In a 2009 study⁹, researchers used a treadmill (TM) and daily activities to compare the RT3 uniaxial and triaxial accelerometer for the prediction of estimated energy expenditure. The subjects consisted of 212 individuals who participated in TM tests at varied speeds and grades along with other activities including moving a box, ascending and descending stairs, and another random assigned activity. Following a 4 hour fast the subject's height and weight were measured along with the resting metabolic rate for 15 minutes using a metabolic analyzer (MedGem). At a lab the subjects completed the TM or daily activities in random order. There were 6 bouts for the TM test consisting of 1.34, 1.56, or 2.23 meters per second for 7 minutes each at a grade of 0% or 3% with 4 minutes of rest between bouts. The daily activities consisted of ascending or descending stairs for 7 minutes, moving a 4.5 pound box, or two randomly selected activities of household chores or sports activities. During the tests total energy expended was measured in kilocalories per minute using a portable metabolic analyzer (Oxygen Mobile). Data from the accelerometer was gathered for vertical, medial-lateral, and anterior-posterior planes for the uniaxial measurement and vector magnitude using a proprietary algorithm for triaxial measurement.

The accelerometer overestimated all the treadmill tests by 9.0% (0.54 ± 0.05 kcal/min⁻¹) and underestimated all the daily activities by 34.3% (-1.75 ± 0.11 kcal/min⁻¹). An underestimation was seen from activities that involved mostly upper body movements (-24.4%-64.5%) but an overestimation was seen from activities that used mostly the lower body (+20.6%-55.0%). Estimated energy amounts were similar for both the uniaxial and triaxial components when using the RT3 model to measure for both at the same time. A separate model using only triaxial measurements may improve its accuracy of estimated energy.

In a 2008 study²³, researchers analyzed population and gender specific epidemiology of accelerometer measured steps during the day. The study examined the accelerometer's measurement uncensored with inactivity steps counted and censored without steps counted during times of inactivity. This was done by a post hoc elimination of low-intensity steps. The subjects consisted of 3744 participants, aged 20 years and over, who wore an accelerometer (ActiGraph AM-7164) for 10 hours a day for 7 days, 4 days of which were used for the research results. Data was recorded every minute and steps were counted to reach the 1440 minutes per day totals. Daily steps were averaged over the allotted time for analysis. The analysis was divided into activity intensity categories of vigorous or moderate and inactive or light. A category was established for different groups based on average number of steps during the day: basal activity <2500, limited activity 2500-4900, low activity 5000-7499, somewhat active 7500-9999, active 10000-12499, and highly active >12500.

The results showed that the average number of steps taken was 9676 ± 107 uncensored and 6540 ± 106 censored steps per day and males on average wore the device

30 minutes longer than females. Males took 1696 more censored and 1675 more uncensored steps per day. The highest numbers of steps were recorded in the lowest intensity for both genders. For males it was 47% of uncensored and 66.9% of censored steps and for females 46.7% uncensored and 69.5% censored. Vigorous activity was a small percentage at 4.9% uncensored and 6.9% censored in males and 7.3% uncensored and 10.9% censored in females. Compared to other samples in similar studies of accelerometer-determined steps per day in free-living situations, the researchers feel that the accelerometer overestimated the number of steps taken during the day and a more valid conversion factor is needed to determine the results. The average of 10,000 steps in this study is compared to two other studies; one counted 6,800 steps and another 5,900.

In a 2001 study¹³, researchers used 17 (m=9, f=8) young endurance runners aged 18-24 years, to measure biomechanics and how it relates to the economy of running by measuring factors such as joint kinetics and electromyographic (EMG) activity. The study was conducted on an indoor track using 9 different running speeds. The subjects participated in submaximal runs at 3.25, 4.00, 4.50, or 5.00 meters per second for 3 minutes each with a 3 minute rest between bouts. Following a 10 minute recovery the subjects ran at 5.50, 5.75, 6.00, and 6.50 meters per second for 1 minute with a 5 minute rest between each test. Following a 15 minute rest after the other tests the subject ran at maximal speed for 30 meters.

Speed was measure by an electrical car which rode along side of the subjects using the pointer of the speedometer which was connected to a pulse meter. The gas exchanged from the subjects inspiration and expiration was collected using a gas analyzer (SensorMedics V max). HR was measured using a HR monitor (Polar Electro Sport

Tester). Joint movement was measured using 2-D video analysis (Motus). Blood lactate was also measured at rest and 2 minutes after each test. EMG activity for the muscles used was recorded telemetrically using surface electrodes (Glonner). Ground reaction force and kinematic records were also observed.

The results indicated that energy expenditure increased linearly with oxygen consumption with increased running speed. The results also suggest that running economy changes with an increase in running speed. There was an increase in EMG activity of the biceps femoris muscles resulting in an increase in energy expenditure due to an increase in power output from the working muscles. The greatest amount of power output was seen in the push off phase of contact during the running stride. The study also suggested that low performance may be due to poor technique by limiting action of the hamstring muscles.

In a 2004 study²⁰, researchers compared the mechanical costs and energy expenditure of runners according to their level of training. Subjects were selected from three different training levels: highly trained (n=7) from the French marathon team (m=3, f=4), well trained (n=8) who competed in national competition, and non-trained (n=6) physical education students. The tests were all done on a 400 meter synthetic track. The highly trained group ran for 30 minutes at a constant velocity determined by the average speed of their best marathon time. A bicycle with a calibrated speedometer followed the subject closely allowing the speed to be measured. The well trained and non-trained groups completed two exhaustive bouts. The first bout was incremental which increased from 12 km·h⁻¹ in 3 minute stages at 1 km·h⁻¹, with a 30 second rest between stages, to exhaustion. During this test VO₂ max and blood lactate levels were

measured. The second test used VO_2 max and blood lactate levels to set the velocity of work at 50% work rate difference between lactate threshold and VO_2 max for the well trained runners and 95% VO_2 max levels were set for the non-trained runners.

The energy cost of running was measured using an indirect calorimeter (Cosmed K4b²). Mechanical cost was measured using video sequences recorded on a digital video camera (Sony TRV 900) which was then downloaded and digitized to a computer then transformed to bitmap pictures.

Energy expenditure between the highly trained runners and the less trained runners showed no significant difference. Potential energy cost was significantly lower in the two trained groups as compared to the non-trained group. Internal mechanical energy cost was significantly higher in the highly trained group as compared to both the well trained and non-trained group. Therefore, the cost of energy may be due to the impacts from stride and impact from the load rather than from training.

In a 2003 study⁸, researchers determined if body size was a good predictor of energy expenditure using an activity monitor (Manufacturing Technology, Inc) during over ground walking. Fifty-eight subjects (m=29, f=28) aged 20-42 years, walked at a self paced speed for three separate tests on an indoor track. Data from measured VO_2 using indirect calorimetry (Aerosport) and output from the activity monitor, using an accelerometer, were gathered during the tests. This information was used to generate new prediction equations based on the activity monitor outputs.

Prior to the tests age, gender, body mass, and height were recorded. During the warm up strides were measured for slow, intermediate, or fast walking speeds. These

were then used to control the subject's rate of walking during the tests. Each subject walked at all the speeds consecutively for 6 minutes to a metronome with a 2 minute break in between. An average from the last three minutes of each test were used to analyze output in counts per minute, stride rate in steps per minute, and walking speed in meters per second. A regression relationship between METs and the activity monitor output was measured. The results using just METs were highly significant ($r=0.82$). The second results that added body height were also highly significant ($r=0.84$). Thus, using body size to determine a more accurate measurement of energy expended has no greater advantage while using an activity monitor.

In a 2009 study¹⁵, researchers compared gender differences for physiologic and perceptual responses during running. Twenty marathon runners ($m=10$, $f=10$) average age for males was 41 ± 11.3 and females 42.7 ± 11.7 years, were tested during both a 1 hour treadmill run and a running economy test. The 1 hour treadmill test was run at a recent marathon pace for each subject. The running economy test was run at speeds of 134, 168, and 188 meters per minute for 5 minutes at each speed. Prior to the testing, body composition (dual energy x-ray absorptiometry) and VO_2 max (Sensormedics metabolic cart) were measured. During the test, oxygen uptake, carbon dioxide production, and pulmonary ventilation were measured, as well as HR using a HR monitor (Polar), and rating of perceived exertion (RPE).

A linear increase was seen in VO_2 , percent VO_2 max, HR, and RPE over time, however, RER decreased in all subjects. The only difference between genders during the 1 hour test was the VO_2 max in which the males reached 67.7% of their max while the females reached 76.3%, although the males ran the test at a faster speed than the females.

There were also no significant differences in the variables measured during the economy running test.

In summary, HR can be used as an accurate means to measure estimated energy expenditure if other factors are calculated into the equation such as gender, age, and body weight. When measuring speed and distance GPS units can provide accurate measurements, though some inaccuracies may occur when measuring on curved paths. Accelerometers can provide accurate measurements of distance and speed on flat terrain, but some inaccuracies occur during uphill to downhill grade changes. Accelerometers may overestimate energy expenditure when the lower body is the primary source for movement possibly due an overestimation of steps measured. Accelerometers may underestimate energy expenditure for daily activity measurements due their inability to accurately measure upper body movements. There was no significant difference between training level and gender, but body weight has a significant factor in determining energy expenditure in runners.

CHAPTER III

METHODS

Research Design

An experimental research design was used. The independent variable was the type of device: Garmin (Forerunner 405CX GPS) and the Nike + iPod. The dependent variables were distance, speed, and energy expenditure. The study was delimited to physically active individuals who could run at least 3 miles continuously.

Subjects

The subjects were a convenience sample of volunteers consisting of 15 runners recruited from the Cleveland running community. The subjects consisted of 9 males and 6 females ranging in age from 18-55 years. An informed consent form (Appendix A) was signed by each subject prior to the start of the study. Subjects were given the AHA/ACSM pre-screening questionnaire (Appendix B) and only low risk subjects were used.

The tests were conducted on weekend mornings or weekday evenings. Weather also factored into the scheduling with tests cancelled for rain. Due to computer battery capacity, only 2 subjects could be scheduled consecutively. Therefore, the testing of subjects was conducted over a 2 month period.

Experimental Procedures

This study used two commercially available devices that measure energy expenditure, distance, and speed during overground running.

The Garmin Forerunner 405CX GPS (Appendix C) and the Nike + iPod (Appendix D) were the two devices compared during this study. The accuracy of estimated energy expenditure was compared to that measured by a portable indirect calorimeter (Cosmed K4b²). The accuracy of the distance was compared against a three mile course which was measured using a calibrated measuring wheel prior to the test. The accuracy of speed was determined by dividing the subject's time by the three mile distance. The accuracy and validity of these devices were measured during a simultaneous data collection period.

The study was conducted on a wooded paved trail with a slight grade in a Cleveland area Metro Park. The three mile course and one quarter mile calibration distance was measured and marked on the trail prior to the experiment using a calibrated measuring wheel. The course was measured to the right hand and left hand side of the center line of the path.

Prior to arriving at the location of the study, the calorimeter was calibrated using calibration gases (16% O₂, 4% CO₂) and a 3 liter syringe. A small laptop computer was

brought to the testing site which was used for the data collection. The subject's height, weight, and age were entered into the computer and ID was assigned to the subject. Recorded on the data sheet were atmospheric conditions consisting of wet and dry bulb temperature and cloud cover.

The laptop was placed on bicycle handle bars and shrink-wrapped in place. The receiving unit was placed on the rack over the back wheel and held in place by elastic bands. (Appendix E) The researchers rode along with the subject on bicycles to receive data from the portable calorimeter unit and direct the subjects on the proper side of the path, path directions, and turnaround point.

The subject's weight was entered into the iPod and weight, height, gender, birth date, and estimated HR max was entered into the GPS device prior to the start of the test, respectively. The chest strap for measuring HR for the GPS unit as well as the calorimeter, was placed around the chest of the subject and the accelerometer for the Nike was placed on the top of the subject's right shoe in a pouch attached to the shoe laces. The calorimeter was placed on a harness over the subject's shoulders and strapped around the subject's chest and back. The face mask was placed covering the subject's mouth and nose so as to not allow air to escape. The GPS unit was placed on the subject's wrist and the iPod placed in the subject's hand (Appendix E).

The calibration of the Nike +iPod was conducted first. The subject was asked to press the center button on the iPod at the start of the run from the measured starting line near the parking lot. The subject ran to the quarter mile marker on the trail and stopped running. The Nike + iPod was stopped by pressing the center button at the time the

subject stopped running. The researchers checked if the calibration was successful and if so, the test continued. If the calibration was not successful, the calibration process was repeated.

The 3 mile test began at the quarter mile mark and was run on an out and back course ending at the measured starting line near the parking lot. The calorimeter needed a brief calibration before being started. This was conducted on the trail prior to the start of the 3 mile run. When the calibration was complete, the 3 devices (GPS, Nike +iPod, and calorimeter) were started simultaneously and the subject began to run. One researcher started the calorimeter, one researcher started the GPS unit, and the subject started the Nike +iPod.

The subjects ran at a comfortable pace for the three miles, making a turnaround at the measured point on the course. At the end of the 3 mile course all measuring devices were stopped simultaneously by the same individual who started it.

The data from all devices were collected and recorded on a data sheet for each subject along with ID, age, weight, gender, wet bulb, dry bulb, and cloud cover.

Data Analysis

Descriptive statistics were obtained. Inferential statistics (one-way ANOVA) were used to assess treatment differences due to the independent variable, device type (Garmin Forerunner 405CX GPS and the Nike + iPod) on the dependent variables (energy expenditure, distance, and speed). Inferential statistics were also used to assess treatment differences due to the independent variable, device type, on the dependent

variables, when assessing results between genders. SPSS (version 16.0) was used for all analyses with .05 used as the level of significance.

CHAPTER IV

RESULTS AND DISCUSSION OF DATA

Results

Energy expenditure was calculated by indirect calorimetry using the Cosmed K4b² portable CO₂ and O₂ analysis system. Estimated energy expenditure was calculated using the Garmin Forerunner 405CX GPS and Nike +iPod. The two devices were compared to the indirect calorimeter measurements. The two devices were also compared to a measured distance (3 miles) using a calibrated measuring wheel. Average speed (mph) of the devices was calculated by taking the time it took the subject to run the 3 mile course divided it by the distance measured from each device (GPS and Nike). The results are organized by comparing energy expenditure, distance, and speed.

Comparison for Energy Expenditure

The GPS unit and the Nike iPod were compared to the indirect calorimeter to determine the accuracy of estimating energy expenditure (kcal). The results are presented in Table 1.

As shown in Table 1, the mean for the measured energy expenditure (kcal) of the GPS was 307.6 ± 103.9 and the indirect calorimeter was 392.4 ± 74.9 . The GPS to indirect calorimeter comparison's mean difference was -84.8 ± 103.9 which was significantly ($p=.007$) less. The mean for the Nike was 391.4 ± 60.4 and for the indirect calorimeter was 392.4 ± 74.9 . The Nike to indirect calorimeter comparison's mean difference was -1.0 ± 60.3 and was not significantly different ($p=.973$). The mean for the GPS was 307.6 ± 103.9 and the Nike was 391.4 ± 60.4 . The GPS to Nike comparison's mean difference was -83.8 ± 60.4 and was significantly ($p=.008$) less.

Table 1. Comparison of Energy Expenditure (kcal)

Variable	Mean \pm SD (kcal)	Mean Difference (kcal)	Sig.
GPS	307.6 ± 103.9	-84.8 ± 103.9	.007*
Indirect calorimeter	392.4 ± 74.9		
Nike	391.4 ± 60.4	-1.0 ± 60.4	.973
Indirect calorimeter	392.4 ± 74.9		
GPS	307.6 ± 103.9	-83.8 ± 60.4	.008*
Nike	391.4 ± 60.4		

*Significant difference ($p<.01$)

A scatter plot (Figure 1) was used to more closely display individual differences for energy expenditure of the devices and how the GPS and Nike worked better for some

subjects than for others. As seen in Figure 1 the GPS unit was more inaccurate for most subjects while the Nike was more accurate for most of the subjects as compared to the indirect calorimeter.

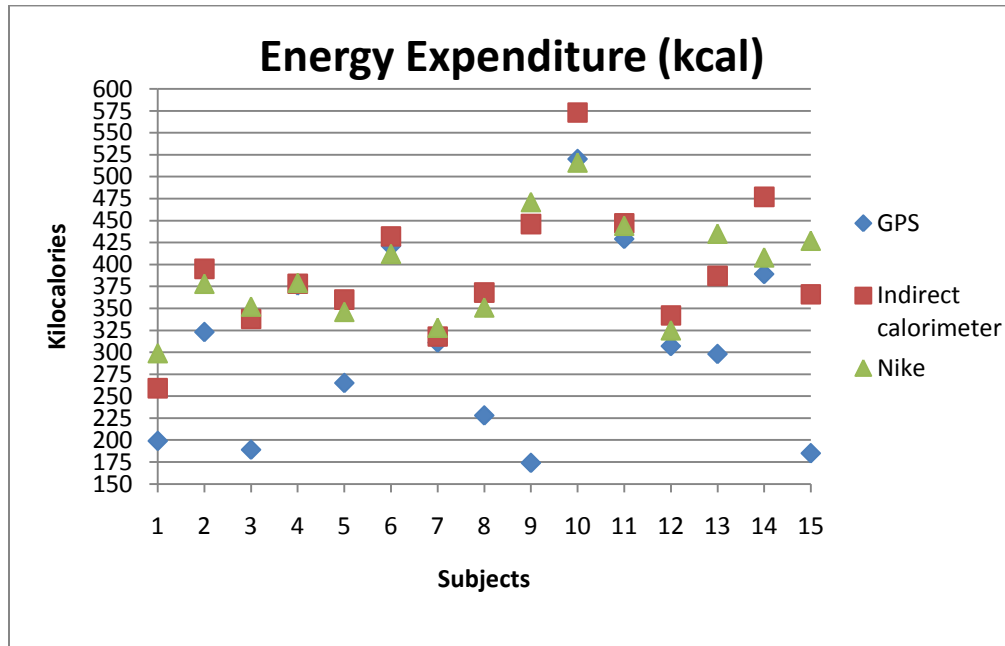


Figure 1. Scatter plot of energy expenditure by device for each subject (n=15).

Comparison for Distance

The accuracy of the two devices for determining distance is provided in Table 2. These results were all compared against a measured distance (3 miles) using a calibrated measuring wheel. The mean for the GPS was 2.97 ± 0.02 and the measured distance was 3.00. The GPS compared to the measured distance's mean difference was -0.03 ± 0.02 and was not significantly different ($p=.506$). The mean for the Nike was 3.20 ± 0.21 and the measured distance was 3.00. The Nike compared to the measured distance's mean difference was $.20 \pm 0.21$ and was significantly ($p=.0001$) greater. The mean for the distance (miles) of the GPS was 2.97 ± 0.02 and the Nike was 3.20 ± 0.21 . The GPS

compared to the Nike's mean difference was -0.23 ± 0.21 and was significantly ($p=.0001$) less.

Table 2. Comparison of Distance (miles)

Variable	Mean\pmSD (miles)	Mean Difference (miles)	Sig.
GPS Measured Distance	2.97 ± 0.02 3.00	-0.03 ± 0.02	.506
Nike Measured Distance	3.20 ± 0.21 3.00	0.20 ± 0.21	.0001*
GPS Nike	2.97 ± 0.02 3.20 ± 0.21	-0.23 ± 0.21	.0001*

*Significant difference ($p < .01$)

A scatter plot by subject (Figure 2) illustrates the distance measured by both devices as compared against a measured known distance (3miles). This provides a view of the individual differences for each device by subject. As seen in Figure 2, the GPS unit provided an accurate measurement of distance for all subjects as compared to the measured distance of 3 miles. However, the Nike did not. As shown, a few subjects had similar measurements from both devices whereas others had dissimilar measurements from both devices.

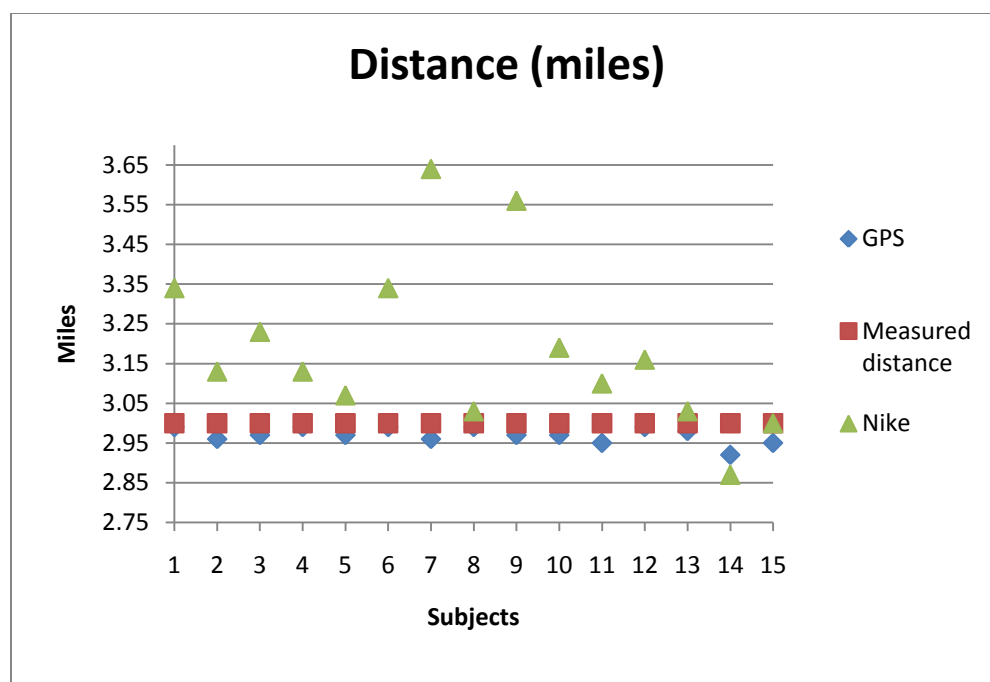


Figure 2. Scatter plot of distance (miles) by device for each subject (n=15).

Comparison for Speed

The results for calculated speed of the two devices are provided in Table 3. The average speed was calculated using the distance measured by the device divided by the subject's time to complete the 3 mile course. As shown in Table 3, the mean for the GPS was 6.87 ± 0.81 and the Nike was 7.39 ± 0.81 . The mean difference between the GPS and the Nike was 0.52 ± 0.81 which was not significantly different ($p=.095$). Since the distance for the GPS was more accurate, the speed would also be more accurate.

Table 3. Speed (mph)

Variable	Mean \pm SD	Mean Difference	Sig.
GPS	6.87 ± 0.81	-0.52 ± 0.81	.095
Nike	7.39 ± 0.81		

The scatter plot (Figure 3) shows the actual speed measurements of both devices and the individual results for all subjects. For some subjects the results were quite similar but for others quite different.

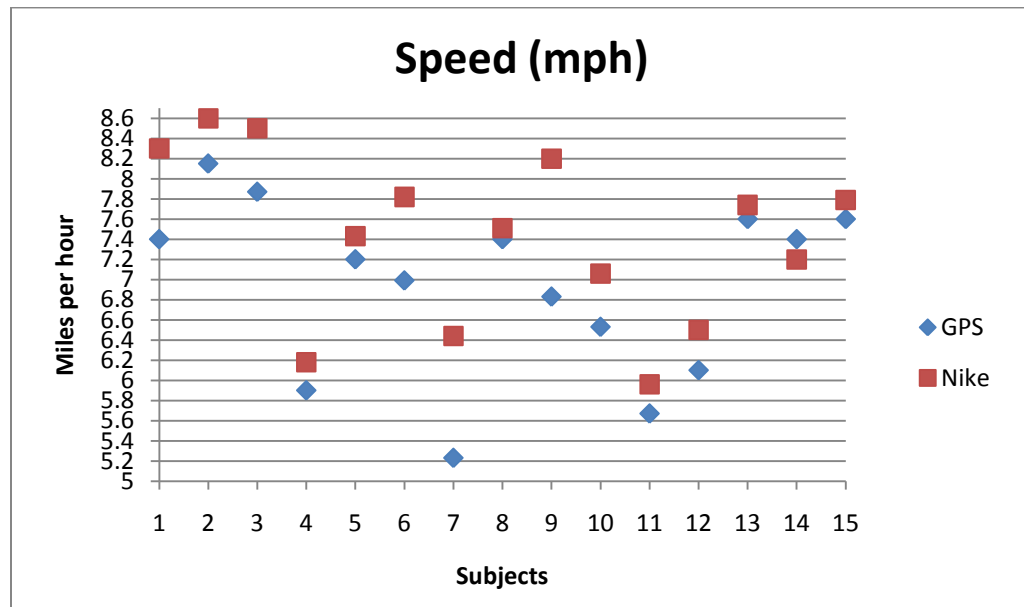


Figure 3. Scatter plot of speed (mph) by device for each subject (n=15).

The Nike provided the more accurate measurement of estimating energy expenditure, whereas the GPS provided more accurate measurement of distance. With the GPS' accuracy for distance it is also assumed that the measurement of speed was more accurate as well with the GPS as compared to the Nike.

Analysis of Gender Differences for Energy Expenditure

The results for gender comparisons of energy expenditure by device are shown in Table 4. This was done to determine if one device was better suited for accurate measurement per gender. As one might expect, males expended more energy than females due to their larger size. The mean for the males' measurement from the GPS was

Table 4. Comparison of Energy Expenditure by Gender

Gender	Variable	Mean±SD kcal	Mean Difference	Sig.
Males	GPS	325.3±124.4	-103.7±124.4	.018*
	Indirect Calorimeter	429.0±69.7		
Females	GPS	281.0±63.9	-56.5±63.9	.057
	Indirect Calorimeter	337.5±43.9		
Males	Nike	427.0±48.5	-2.0±48.5	.961
	Indirect Calorimeter	429.0±69.7		
Females	Nike	338.0±27.2	0.5±27.2	.986
	Indirect Calorimeter	337.5±43.9		
Males	GPS	325.3±124.4	-101.7±48.5	.021*
	Nike	427.0±48.5		
Females	GPS	281.0±63.9	-57.0±27.2	.057
	Nike	338.0±27.2		

*Significant difference (p<.05)

325.3±124.4 kcal and the indirect calorimeter was 429.0±69.7 kcal. The mean difference comparing the GPS to the indirect calorimeter was -103.7±124.4 kcal which was a significantly (p=.018) less in the males. The mean for the females' measurement from the GPS was 281.0±63.0 kcal and the indirect calorimeter was 337.5±43.9 kcal. The mean difference comparing the GPS to the indirect calorimeter was -56.50±63.9 kcal which was not significantly different (p=.057) in the females. The male's mean difference comparison was -103.7±124.4 kcal which was greater than the females mean

difference which was -56.5 ± 63.9 kcal. For both gender's the GPS underestimated energy expenditure.

The mean difference for the males' measurement from the Nike was 427.0 ± 48.5 kcal and the indirect calorimeter was 429.0 ± 69.7 kcal. The mean difference comparing the Nike to the indirect calorimeter for males was -2.0 ± 48.5 kcal which was not significantly different ($p=.961$). The mean difference for the females' measurement from the Nike was 338.0 ± 27.2 kcal and the indirect calorimeter was 337.5 ± 43.9 kcal. The mean difference comparing the Nike to the indirect calorimeter for females was 0.5 ± 27.2 kcal which was not significantly different ($p=.986$). The mean difference comparison for the males was -2.0 ± 48.5 kcal which was greater than the females which was 0.5 ± 27.2 kcal. For both genders, the Nike values were quite similar to the indirect calorimeter.

The mean for the males' measurement from the GPS was 325.3 ± 124.4 kcal and from the Nike was 427.0 ± 48.5 kcal. The mean difference comparing the GPS to the Nike was -101.7 ± 48.5 kcal which was significantly lower ($p=.021$). The mean for the females' measurement from the GPS was 281.0 ± 63.9 kcal and the indirect calorimeter was 337.5 ± 43.9 kcal. The mean difference comparing the GPS to the Nike was -57.0 ± 27.2 kcal which was not a significant difference ($p=.057$). The mean difference comparison for the males was -101.7 ± 48.5 kcal which again was almost twice that of the females which was -57.0 ± 27.2 kcal. For both genders, the GPS was lower than the Nike.

Analysis of Gender Differences for Distance

The results for gender comparisons of distance by device are shown in Table 5. Running stride or gait may change during a run due to fatigue or fitness level. A

Table 5. Comparison of Distance by Gender

Gender	Variable	Mean±SD miles	Mean Difference	Sig.
Males	GPS	2.96±0.02	-0.04±0.02	.518
	Measured Distance	3.00		
Females	GPS	2.98±0.01	-0.02±0.01	.813
	Measured Distance	3.00		
Males	Nike	3.18±0.21	0.18±0.21	.004*
	Measured Distance	3.00		
Females	Nike	3.23±0.23	0.23±0.23	.009*
	Measured Distance	3.00		
Males	GPS	2.98±0.01	0.22±0.21	.001*
	Nike	3.18±0.21		
Females	GPS	2.98±0.01	0.25±0.23	.006*
	Nike	3.23±0.23		

*Significant difference (p<.01)

comparison between genders for the measurement of distance was conducted to see if one device performed better per gender. The mean for the males' measurement from the GPS was 2.96±.02 miles and the measured distance was 3.00 miles. The mean difference for males comparing the GPS to the measured distance was -0.04±0.02 miles which was not a significant difference (p=.518). The mean for the females' measurement from the GPS was 2.98±0.013 miles and the measured distance was 3.00 miles. The mean difference for females comparing the GPS to the measured distance was -0.02±0.01 miles, which was not significant (p=.813). The mean difference comparison for the males was -0.04±0.02

miles which was greater than that of the females of -0.02 ± 0.01 miles. For both genders, the Nike significantly overestimated the distance.

The mean for the males' measurement from the Nike was 3.18 ± 0.21 miles and the measured distance was 3.00 miles. The mean difference for males comparing the Nike to the measured distance was 0.18 ± 0.21 miles, which was a significant difference ($p=.004$). The mean for the females' measurement from the Nike was 3.23 ± 0.23 miles and the measured distance was 3.00 miles. The mean difference for the comparison of the Nike to the measured distance was 0.23 ± 0.23 miles, which was significant ($p=.009$). The mean difference comparison for males was 0.18 ± 0.21 miles which was less than the females which was 0.23 ± 0.23 miles. Both gender's measurement had a positive difference.

The mean for the males' measurement from the GPS was 2.96 ± 0.02 miles and the Nike was 3.18 ± 0.21 miles. The mean difference for males comparing the GPS to the Nike was 0.22 ± 0.21 miles, which was a significant difference ($p=.001$). The mean for the females' measurement from the GPS was 2.98 ± 0.01 miles and the Nike was 3.23 ± 0.23 miles. The mean difference for females for the GPS compared to the Nike was 0.25 ± 0.23 miles, which was significant ($p=.006$). The mean difference comparison for males was 0.22 ± 0.21 miles which was less than the females which was 0.25 ± 0.23 miles. For both genders, the Nike significantly overestimated distance as compared to the GPS.

Analysis of Gender Differences for Speed

The results for gender comparisons of distance by device are shown in Table 6. As expected the males on average ran faster than the females. The mean for the males'

Table 6. Comparison of Speed by Gender

Gender	Variable	Mean±SD Avg Speed mph	Mean Difference	Sig.
Males	GPS	7.100±.6837	-.5222±.7678	.147
	Nike	7.622±.7678		
Females	GPS	6.533±.9288	-.5167±.8167	.330
	Nike	7.050±.8167		

measurement of speed for the GPS was 7.1 ± 0.7 mph and the Nike was 7.6 ± 0.8 mph. The mean difference was -0.52 ± 0.8 mph which was not significantly different ($p=.147$). The mean for the females' measurement of speed for the GPS was 6.5 ± 0.9 mph and the Nike was 7.1 ± 0.8 mph. The mean difference was -0.5 ± 0.8 mph which was not significantly different ($p=.330$). The mean difference comparison for males was -0.5 ± 0.8 mph and the females was -0.5 ± 0.8 mph. For both genders, the GPS was lower than the Nike.

The only significant difference observed when comparing devices in genders was a greater underestimation of estimated energy expenditure from the GPS in males as compared to females. Speed and distance had no significant difference when observing results of gender when comparing devices.

Discussion

This study compared the accuracy of the Garmin Forerunner 405CX GPS and the Nike + iPod for energy expenditure, distance, and speed during 3 miles of overground running. Since both of these devices are new to the market no previous research was conducted on the particular models used in this study. There were few studies measuring

energy expenditure using GPS units² and accelerometers^{2,6,9,11,23}. Many studies using HR monitors have been conducted to measure energy expenditure^{3,7,12,13}. There also have been studies to measure running economy¹³, trainability²⁰, or body size⁸ to measure energy expenditure. Both units used in this study used body weight and an algorithm to estimate energy expenditure. The GPS device also included age, estimated max HR, height, and gender. The GPS unit included a chest strap to measure heart rate as well.

The energy expenditure results for the GPS and Nike units were compared against a Cosmed K4b² portable calorimeter. The energy expenditure measured from the GPS unit was significantly less by 84.8 kcal than the indirect calorimeter with an underestimation of the GPS device. These results do not agree with previous studies in that there is a linear relationship between energy expenditure and mechanical power^{13,21}. The use of a heart rate monitor with the GPS unit does not agree with previous studies in the prediction of energy expenditure^{3,7,12}. Heart rate alone used in prior studies to estimate energy expenditure has overestimated energy expenditure³, but when age, gender, and weight were factored in the accuracy for estimated energy expenditure improved^{7,12}. There was a variety of training levels among subjects and no consistency in energy expenditure was shown between the subjects as compared to the devices. This supports the prior study that suggests that trainability does not factor into energy expenditure but rather stride and load impact²⁰. The Nike was not significantly different than the indirect calorimeter. These results do not agree with previous studies in that there is an overestimation when measuring lower body movements with accelerometers^{6,9}. Previous studies^{10,11,23} as well as this study found an overestimation in

steps, which should linearly show an overestimation in estimated energy expended, which was not measured in this study.

The distance results for the GPS and Nike units were compared against a measured distance using a calibrated measuring wheel. The distance measured by the GPS unit was not significantly different than that of the known distance which agrees with results from previous studies^{4,22}. The distance was accurately measured even with change in stride and speed by some of the subjects, agreeing with a prior study⁴. The course used in this study was on a path in a wooded area and found no inaccuracies due to tree cover or curving of the path as a previous study found²². The distance measured by the Nike was significantly greater by 0.20 miles than the known distance. This suggests that similar problems found in previous studies with elevation change and change in gait^{2,9} or an underestimation of steps taken²³ may have contributed to the inaccuracy of this device. Accelerometers in previous studies have measured an overestimation of steps^{9,23}, which agree with the results found in this study.

The average speed results for the GPS and Nike units were compared against each other. The average speed was calculated by dividing the distance measured by the device by the time it took the subject to complete the test. While the Nike speed was 0.5 miles per hour greater than the GPS, this was not significant. These results agree with previous studies that GPS units^{4,22} and accelerometers² are accurate devices for measuring speed during running.

The results from each of the devices were also compared by gender. The results showed significant differences for energy expenditure in the males, but not the females

for the GPS as compared to indirect calorimetry and the Nike. Males are generally larger, weigh more, and run at a faster speed than females. This suggests that body mass has an impact on results as well as running style and trainability as suggested in previous studies^{13,20} for energy expended. The GPS unit underestimated the energy expended for both genders, but more so for the males in this study than the females. This does not agree with previous studies that suggest gender incorporated into the factoring of estimated energy expenditure is important for accurate results^{3,7,12}. Gender did not affect the results for distance or speed from either of the devices in this study.

Bottom line

The more accurate device for runners looking to closely measure energy expenditure is the Nike. Those that are looking to closely measure distance and speed, the more accurate device is the GPS. For a few subjects both devices were quite accurate for all variables measured. Others had inaccuracies in one or all variables measured. Some individuals may be better suited for one type of device than for another.

CHAPTER V

SUMMARY AND CONCLUSION

Summary

New devices are frequently marketed to help runners and athletes obtain and record measurements of physical activity. Two such devices are GPS units and accelerometers. Previous research on these devices support the accuracy of some of the measurements derived from these devices. The purpose of this research study was to compare the accuracy of distance, speed, and energy expenditure of overground running with two different devices: the Garmin Forerunner 405CX GPS and the Nike + iPod.

Fifteen runners from the local Cleveland running community were recruited for this study. The subjects consisted of 9 males and 6 females aged 18-55 years. Prior to the start of the test, the subjects were instructed to run a quarter mile calibration for the Nike + iPod. Upon completion of the calibration, the subjects completed a 3 mile

measured distance run with the devices tracking progress for energy expenditure, distance, and speed simultaneously.

Significant differences were seen comparing the indirect calorimeter to the GPS unit ($p=.007$) and when comparing the GPS unit and the Nike unit ($p=.008$) during the measurement for energy expenditure. Significant differences were also seen when comparing the measuring wheel and the Nike unit ($p=.0001$) and when comparing the GPS unit and Nike unit ($p=.0001$) during the measurement for distance. However, there was no significant difference seen between the speed between the GPS unit and the Nike unit. The only significant gender difference between the devices was an overestimation for energy expenditure by the GPS in males.

Conclusion

This study showed an inaccurate measurement of energy expenditure during running while using the Garmin Forerunner 405CX GPS but an accurate measurement of energy expenditure from the Nike +iPod during overground running on a 3 mile course. Also shown in this study was an accurate measurement of distance using the Garmin Forerunner 405CX GPS, but an inaccurate measurement of distance using the Nike +iPod. These inaccuracies of distance from the Nike +iPod may have been seen due to a change in the subject's running gait due to fatigue or elevation changes throughout the run. However, an accurate measurement of speed was seen from the Garmin Forerunner 405CX GPS and Nike +iPod during this study. There was no significant difference between males or females for either of the devices used for distance or speed. Males,

however, had an overestimation of energy expended from the GPS unit than did females during this study.

Limitations

The following limitations were noted for this study:

1. The 3 mile distance of this study may have not been long enough to allow the devices to correct for changes in gait, stride length, and force from the runners.
2. There was a wide range of running abilities and more experienced runners may have a more stable stride length and gait.
3. An even distribution of genders may also have benefitted due to size, strength, and running ability of males versus females.

Applications

The Garmin Forerunner 405CX GPS can be used to accurately measure distance and speed during outdoor overground running. Distance and speed are desirable measurements for many runners and therefore this device would be helpful to those looking to closely track these. However, those looking to closely track energy expenditure would not receive adequate results from the GPS unit and therefore, the Nike +iPod would be a better choice. However, the Nike unit may not be an ideal choice for those closely tracking distance during outdoor running.

Future Research

Both of the devices measured in this study were new on the market at the time of this research study. Future research is needed to validate this study for all variables

measured. This study was limited to a 3 mile course, so a longer course or different course lengths could render different results. Also, using runners with similar abilities may be considered.

APPENDICES

APPENDIX A

INFORMED CONSENT FORM FOR PARTICIPATION

Comparing two devices to accurately measure energy expenditure, distance, and speed in overground running

INTRODUCTION

You have been asked to participate in a research study to be conducted for Cleveland State University. The purpose of this study is to compare the accuracy of a GPS unit with heart rate monitor and an accelerometer outdoors while running for 3 miles. Each device will be evaluated after the completion of the 3 mile distance.

The significance of this study is that it may provide information on the accuracy of energy expenditure, distance, and speed in commercially available devices and detect any potential limitations.

PROCEDURES

After a quarter mile calibration prior to the trial, you will be asked to run a distance of 3 miles at a comfortable pace over the measured course while measuring energy expenditure, distance, and speed. You will only have to complete the 3 mile run once as all devices will be used at the same time. The gas exchange collection device will be attached to you by a belt and a mask will be placed over the nose and mouth during the entire test. The GPS has a wrist units and chest strap to collect data. The accelerometer has a sensor which is attached to the each shoe and the information is transmitted to a MP3 unit. It is expected that the trial time will be less than 45 minutes.

RISKS AND DISCOMFORTS

The expected probability of risk is no more than what is expected during a typical exercise session. Typical responses to exercise include increased heart rate, blood pressure, ventilation, and body temperature as well as muscular fatigue. There is a rare possibility of injury, and in some cases, death in relation to the stress of exercise on the body. The methods and expectations for this study will be explained and you will have the opportunity to withdraw at any time without penalty. Also, if you experience any discomfort or feel you are placing yourself at risk during this study, you are free to

discontinue at any time. The devices used for gathering data are available on the market and any risk from using them is negligible.

BENEFITS

Outside of your health benefits of exercise, this study has minimal additional benefits for you other than gaining experience as part of a scientific research project. You may gain an appreciation for the devices used and be able to use this information in your own training program.

CONFIDENTIALITY

To protect privacy, your name will not be used in any documentation of the project. The information, however, may be used for statistical or scientific purposes with your right of privacy retained.

PARTICIPATION

I understand that participating in this project is voluntary and that I have the right to withdraw at any time with no consequences. I understand that if I have any questions about my rights as a participant, I can contact Cleveland State University's Review Board at (216) 687-3630.

Inquiries

Any questions about the procedures used in this project are welcome. If you have any doubts or questions, please ask us for further explanation or call Dr. Sparks at (216) 687-4831, or Christine Mallula at (440) 243-6649.

Participant Acknowledgement

The procedure, purposes, known discomforts and risks, possible benefits to me and to others have been explained to me. I have read the consent form or it has been read to me, and I understand it.

I agree to participate in this program. I have been given a copy of this consent form.

Signature: _____ **Date:** _____

Witness: _____ **Date:** _____

APPENDIX B

Name _____

Date _____

AHA/ACSM Pre-participation Screening Questionnaire

Assess Your Health Needs by Marking all **true statements**

History

You have had:

- ☐ A heart attack
- ☐ Heart surgery
- ☐ Cardiac catheterization
- ☐ Coronary angioplasty (PTCA)
- ☐ Pacemaker/implantable cardiac
- ☐ Defibrillator/rhythm disturbance
- ☐ Heart valve disease
- ☐ Heart failure
- ☐ Heart transplant
- ☐ Congenital heart disease

Recommendations:

If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Other health issues:

- ☐ You have musculoskeletal problems (Specify on back)*
- ☐ You have concerns about the safety of exercise (Specify on back)*
- ☐ You take prescription medication (s) (Specify on back)*
- ☐ You are pregnant

Symptoms

- ☐ You experience chest discomfort with exertion
- ☐ You experience unreasonable breathlessness
- ☐ You experience dizziness, fainting, blackouts
- ☐ You take heart medication

Cardiovascular risk factors

- ☐ You are a man older than 45 years
- ☐ You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal
- ☐ You smoke
- ☐ Your blood pressure is greater than 140/90 mm Hg
- ☐ You don't know your blood pressure
- ☐ You take blood pressure medication
- ☐ You don't know your cholesterol level
- ☐ You have a blood cholesterol >240 mg/dl
- ☐ You have a blood relative who had a heart attack before age 55 (*father/brother*) or 65 (*mother/sister*)
- ☐ You are diabetic or take medicine to control your blood sugar
- ☐ You are physically inactive (*i.e., you get less than 30 minutes of physical activity on at least 3 days/week*)
- ☐ You are more than 20 pounds overweight
- ☐ None of the above is true

If you marked two or more of the statements in this section, you should consult your healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified staff to guide your exercise program.

You should be able to exercise safely without consultation of your healthcare provider in almost any facility that meets your needs.

- Proceed with test if musculoskeletal problems are minor, concerns about safety of exercise are normal, and prescription medications are not for cardiac, pulmonary, or metabolic disease.

Risk Status (Low, Moderate, High): _____

APPENDIX C

Components of the Garmin Forerunner 405CX GPS



APPENDIX D

Components of the Nike +iPod: iPod Nano, receiver, sensor, and sensor case



Components of the Nike +iPod receiver in iPod and sensor attached to the shoe



APPENDIX E

Bicycle set up



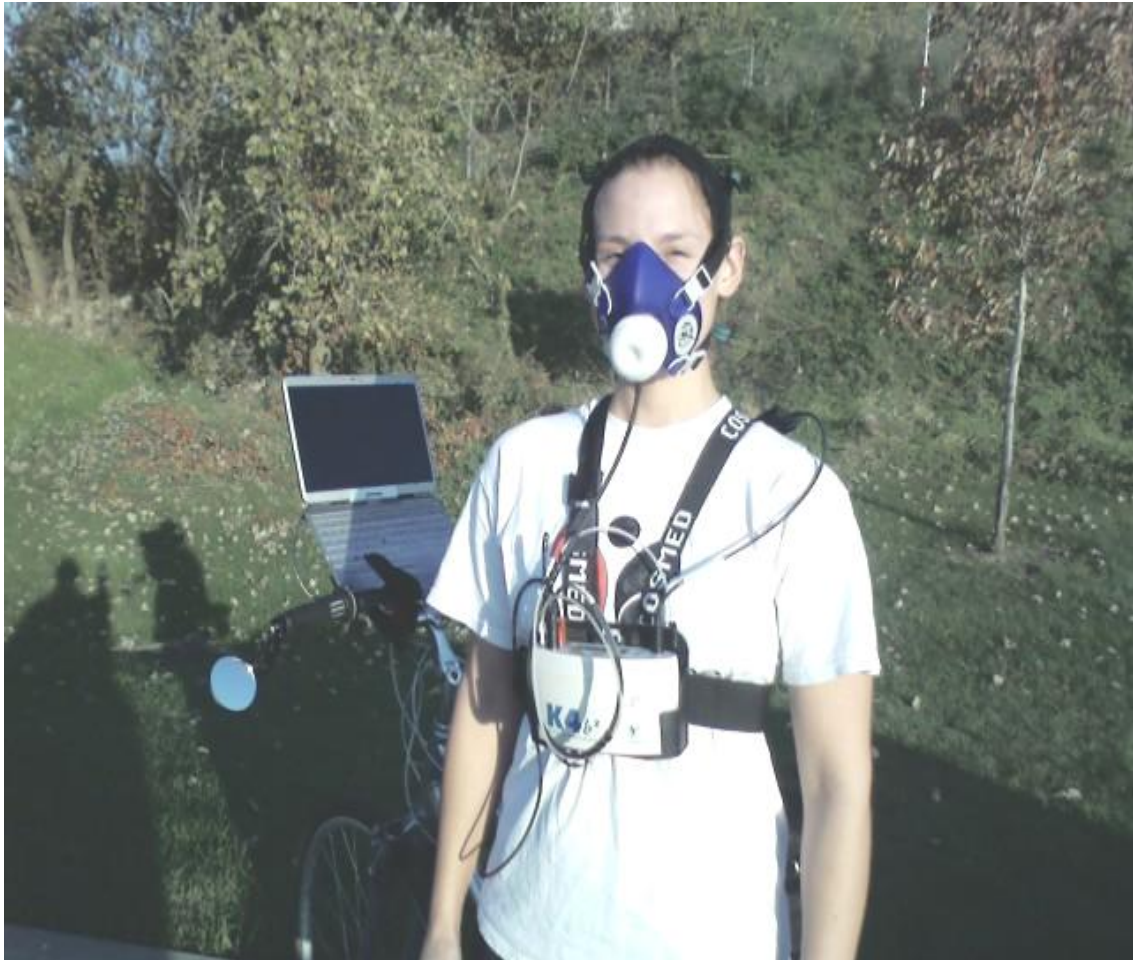
Bicycle set up



Bicycle set up



Subject prior to start of study



Subject on course during study



Subject on course with researcher during study



Subject on course during study



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